

Thirsty Walls - A new paradigm for air revitalization in life support

Completed Technology Project (2015 - 2016)



Project Introduction

Historically, air revitalization is performed by routing air through a complex set of ducts and removal beds that restrict airflow. Microgravity considerations usually require that removal beds are packed with granular solids' these granular beds are relatively heavy, inefficient, and prone to dusting. Liquid based capture systems, such as those found on submarines, have proven to be smaller, more power efficient, and more reliable, but the gas/liquid contactors found in submarines need gravity. Until recently, the only way to use liquid based capture systems in microgravity was to employ a gas permeable membrane. Membranes suffer slow kinetics and are prone to poisoning. Recent developments in additive manufacturing and capillary fluid mechanics makes it possible to directly expose liquids to cabin air in microgravity conditions, and make a microgravity version of a submarine AR system possible. A microgravity compatible gas/liquid contactor also makes it possible to completely re-imagine the AR system: instead of forcing air through a complex series of ducts and beds, air revitalization hardware can take the form of 'Curtains', deployed on the 'Thirsty Walls' of spacecraft. Compared to the traditional HVAC approach used on ISS, Thirsty Walls can reduce the number of rotating pieces of equipment for air revitalization from 19 to 8, and eliminate all of the high pressure and high flow velocity elements. A thirsty walls approach using Monoethanolamine (MEA) the CO₂ capture liquid used in submarines - would make it possible to achieve submarine levels of performance on spacecraft, but this proposal asserts that if the Thirsty Walls approach were used with Ionic Liquids (ILs) instead of MEA, power efficiency could be even greater than that found on submarines. A direct gas/liquid contactor, placed into a Thirsty Walls configuration, pumping an Ionic Liquid for CO₂ capture offers the chance to make a transformational improvement to air revitalization on spacecraft.

Anticipated Benefits

There are possible benefits beyond Human spaceflight: liquid desiccant systems for building AC reduce energy use, especially in humid climates, but liquid desiccant systems are not widely used because spray contactor systems are complicated to operate and only trade in very large scale applications. A simple, continuous, pumped loop liquid desiccant system using a capillary gas/liquid contactor may trade favorable for smaller scale applications.



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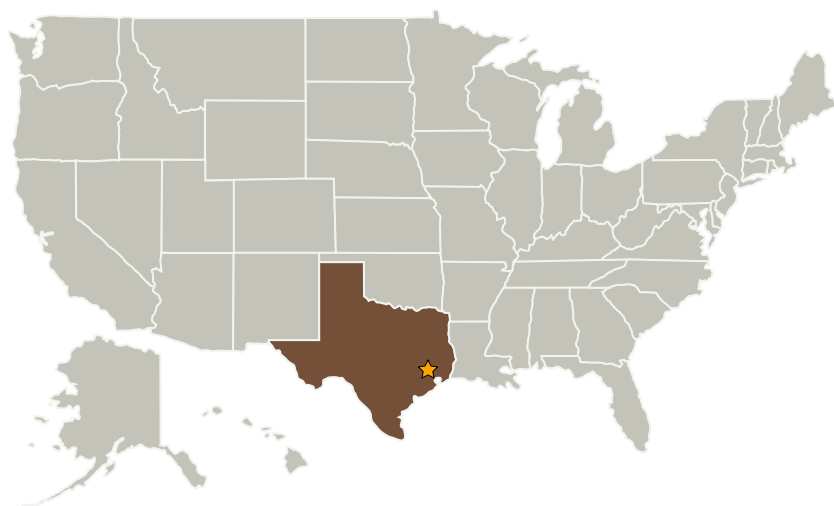
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Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★ Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
Portland State University	Supporting Organization	Academia Alaska Native and Native Hawaiian Serving Institutions (ANNH)	Portland, Oregon
University of Notre Dame(Notre Dame)	Supporting Organization	Academia	Notre Dame, Indiana

Primary U.S. Work Locations

Texas

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

John C Graf


Co-Investigators:Mark M Weislogel
Joan Brenecke

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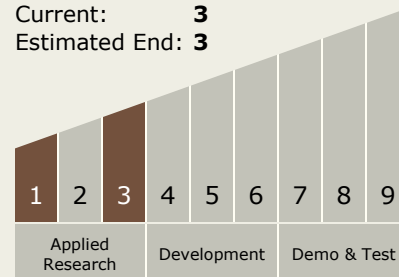


Project Transitions

 **July 2015:** Project Start

Technology Maturity (TRL)

Start: **1**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

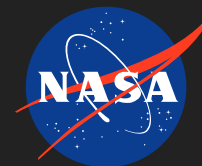
- TX06 Human Health, Life Support, and Habitation Systems
 - └ TX06.1 Environmental Control & Life Support Systems (ECLSS) and Habitation Systems
 - └ TX06.1.1 Atmosphere Revitalization

Target Destination

The Moon

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✓ June 2016: Closed out

Closeout Summary: This Phase I project Summary will be formatted as a series of summary statements, with additional comments. The summary statements are intended to focus on the most significant findings and discoveries - things that the project team knows now, but we didn't know at the beginning of the project. 1) Direct Contact Between Gases is an ECLS System enabling capability. The Phase 1 project focused on CO₂ capture, using direct contact of gases and liquids to facilitate the kinetics of solubility based absorption. At the beginning of the project, we were thinking about the CO₂ capture application, but we were not thinking about ECLS system level impacts. In the course of the phase 1 effort, we realized that many fundamental unit processes in biological and chemical systems (absorption, evaporation, transpiration, distillation, condensation) need direct contact between a gas phase system and a liquid phase system. Capillary technology that enables gas absorption into a liquid helps all ECLS processes that involve gas absorption - it also enables evaporation, transpiration, distillation, and condensation. Fluid management capability is more broadly applicable than we had originally thought. 2) CO₂ capture using liquid sorbents in microgravity is feasible. The phase I project set out to assess feasibility of the CO₂ capture application. Liquid pumping rates are sufficient, high viscosity is tolerable, contact area is sufficient, flow distribution networks are initially large, but there are design paths to reduce system size. It is feasible to use direct gas/liquid contact for CO₂ capture, and with the right designs and sufficient development, these systems promise to be smaller, more power efficient, and more reliable than current systems. 3) There are other ways to contact gases and liquids - but thin film capillary techniques are new, exciting, and have amazing potential. As a result of this phase I project, we are able to put thin film contactors in context with other fluid management systems. Once placed in context, the power and significance of thin film contact becomes apparent. Two existing methods of gas/fluid management are membrane contactors, and wet spray reactors. Membrane contactors have nearly perfect liquid containment, but unacceptably slow kinetics. Wet spray contactors have great kinetics, but no gas/liquid containment. In the balance between kinetics and containment, thin film contactors are in the Goldilocks zone - they have sufficient kinetics and sufficient control. This is new and potentially powerful. 4) ECLS system reliability is the key to exploration missions - the key to reliability is having system attributes that favor reliability. Slow moving, gently sweeping, uniform rate, ambient temperature, ambient pressure systems are more likely to operate reliably than systems that involve vacuum systems, high temperatures, hazardous chemicals, and transient operating conditions. If mission planners place a priority on system reliability, ECLS system developers should focus on processes that have the attributes of reliability. 5) The processes with favorable reliability attributes tend to be biological. Biological systems tend to be ambient temperature, ambient pressure, free of hazardous chemicals, operate at a steady rate, and have the attributes of reliable systems. If Mission Planners want a reliable ECLS system, then ECLS system developers should increase the technical maturity of biological systems. Biological wastewater processes can credibly achieve >98% recovery of water from wastewater. Biological algae based systems can credibly achieve >75% oxygen from CO₂. 6) The single greatest impact on launch mass of an ECLS system is water. The best way to enable biological water processing is to develop a capillary based method of urine capture that doesn't use pretreat chemicals. The ISS potty uses a rotary phase separator that needs strong pretreat chemicals to prevent biofouling and clogging caused by precipitate build up. These pre-treat chemicals, by design, are intended to kill all microorganisms. Rotary phase separators and biological wastewater systems are essentially incompatible. The most enabling thing a fluid mechanics expert can do is to capture urine without the use of pretreat chemicals. This is one of the central technical tasks of the Phase II proposal, the project team has already developed and patented capillary methods of capturing urine in a potty environment. Forward work would involve testing the long term effectiveness of frequent rinsing and occasional system dry out, heat sterilization. 7) There is good, promising, forward design and development work - but no fundamental show stoppers - to develop a thin film liquid sorbent CO₂ capture system. Thin film fluid management starts with several constraints - everything in contact with the air is at the same pressure, and fluids generally move because of a pressure gradient. Thin film fluid flow must rely on capillary gradient, which is a slow and relatively feeble process. The practical limits of fluid movement is just a few centimeters. Phase I identified that a CO₂ capture system needs a traditional closed pipe pumping system to deliver liquids through thousands of ports across a broad area in order to have sufficient contact area. Phase I fluid sizing calculations (shown in detail in this report) show that the pumping and manifold system will likely be bigger and weigh more than the capillary surface. Phase I efforts also show that there are lots of design ideas to make this new system smaller and more effective. It is feasible to make a thin film system. 8) The most capable Ionic Liquids are not presently feasible, but other chemically active liquids can be used to make an effective thin film CO₂ capture device. Dr. Brennecke and the Notre Dame group were key members of the Phase I team, and they are not on the Phase II proposal team. They did nothing wrong, this group is awesome. Two of Dr. Brennecke's students developed candidate ILs with properties that best matched NASA's needs. The candidate IL had amazing capacity (41% by weight) and low regeneration temperatures (significant cyclic performance with regeneration temperatures as low as 60°C). But the IL was not stable, after a few tests it produced a strong odor - indicating chemical breakdown. This has several implications: The first is that Phase I fe

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Project Website:

<https://www.nasa.gov/directorates/spacetech/home/index.html>